Astrobiology Research Priorities for Giant Planets and Exoplanets

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Introduction

The NASA Astrobiology Institute (NAI) formed the Planetary System Formation Focus Group (PSFFG) in 2008 in large part because of the unique opportunity presented by the Astronomy and Astrophysics 2010 Decadal Survey (Astro2010) to provide advice about how the goals and objectives of the 2008 NASA Astrobiology Roadmap might be achieved in the coming decades. The NAI PSFFG thus submitted a White Paper to Astro2010 dealing with the degree to which a range of proposed and existing ground- and space-based telescopes were able to meet the goals and objectives of the 2008 Astrobiology Roadmap. Similarly, another NAI focus group on Habitability and Astronomical Biosignatures (HABFG) prepared a second White Paper for Astro2010 that also dealt with meeting the goals of the 2008 Astrobiology Roadmap. As a discipline, Astrobiology spans the Astrophysics Division at NASA HQ (responsible for space telescopes of astrobiological interest) and the Planetary Science Division (responsible for the Astrobiology Research & Analysis programs). The current White Paper thus will build upon the thrust of these two Astro2010 White Papers, and extend the domain to include Research & Analysis activities of interest for the Giant Planets and Exoplanets panel of the new Planetary Science Decadal Survey (Planet2011).

The NASA Astrobiology Roadmap is updated periodically, and the 2003 version was last updated in 2007-08 and published in 2008 by D. J. Des Marais et al. (Astrobiology, Volume 8, Number 4, pages 715-730). The 2008 Roadmap was reviewed by the Executive Council of the NAI and by the Committee on the Origins and Evolution of Life of the National Academy of Sciences Space Studies Board. The 2008 Roadmap thus represents the most up-to-date, authoritative assessment of the goals and objectives of NASA's astrobiology initiative, and hence is a valuable guide for planning the federal government's investments in astronomy, astrophysics, and planetary science in the coming decades.

The purpose of this White Paper is thus to build directly upon the 2008 Astrobiology Roadmap. Because the science case for NASA's astrobiology efforts has already been developed in full in the published Roadmap, we will not attempt to reproduce that case here, but rather to highlight briefly the scientific rationale for the efforts of most relevance for the Giant Planets and Exoplanets panel of the Planet2011 survey. This White Paper will thus differ from many other White Papers submitted to Planet2011, in that we have the advantage of the head start presented by the 2008 Roadmap.

Astrobiology Roadmap Goals and Objectives

Astrobiology seeks answers to three basic questions: How does life begin and evolve? Does life exist elsewhere in the universe? What is the future of life on Earth and beyond? In order to attempt to answer these three profound questions, the Roadmap lists seven Science Goals, each of which is likely to serve as an active area of research for several decades. Each Science Goal is accompanied by Science Objectives. It is intended that these Science Objectives should receive the highest priority for research in the near term. Because of the intrinsically multidisciplinary nature of astrobiology, involving molecular biology, ecology, planetary science, astronomy, and other disciplines, the Roadmap's Goals and Objective span this same enormous breadth. Given that this White Paper is restricted to the topics to be considered by the Giant Planets and Exoplanets panel of Planet2011, and the fact that in practice giant planets are of limited direct relevance for Astrobiology (except to the extent that they influence the formation and evolution of habitable planets, or support habitable moons, which falls in the domain of other Planet2011 panels), we focus here solely on Exoplanets and hence on the following Goals and Objectives from the 2008 Astrobiology Roadmap (Des Marais et al. 2008):

Goal 1: Understand the nature and distribution of habitable environments in the universe. Determine the potential for habitable planets beyond the Solar System, and characterize those that are observable.

Objective 1.1: Formation and evolution of habitable planets.
Investigate how solid planets form, how they acquire liquid water and other volatile species and organic compounds, and how processes in planetary systems and galaxies affect their environments and their habitability. Use theoretical and observational studies of the formation and evolution of planetary systems and their habitable zones to predict where water-dependent life is likely to be found in such systems.

Objective 1.2: Indirect and direct astronomical observations of extrasolar habitable planets.
Conduct astronomical, theoretical, and laboratory spectroscopic investigations to support planning for and interpretation of data from missions designed to detect and characterize extrasolar planets.

Goal 3: Understand how life emerges from cosmic and planetary precursors. Perform observational, experimental, and theoretical investigations to understand the general physical and chemical principles underlying the origins of life.

Objective 3.1: Sources of prebiotic materials and catalysts.
Characterize the exogenous and endogenous sources of matter (organic and inorganic) … in other planetary and protoplanetary systems.

Goal 7: Determine how to recognize signatures of life on other worlds... . Identify biosignatures that can reveal and characterize past or present life in ... remotely measured planetary atmospheres and surfaces. Identify biosignatures of distant technologies.

Objective 7.2: Biosignatures to be sought in nearby planetary systems.
Learn how to identify and measure biosignatures that can reveal the existence of life or technology through remote observations.

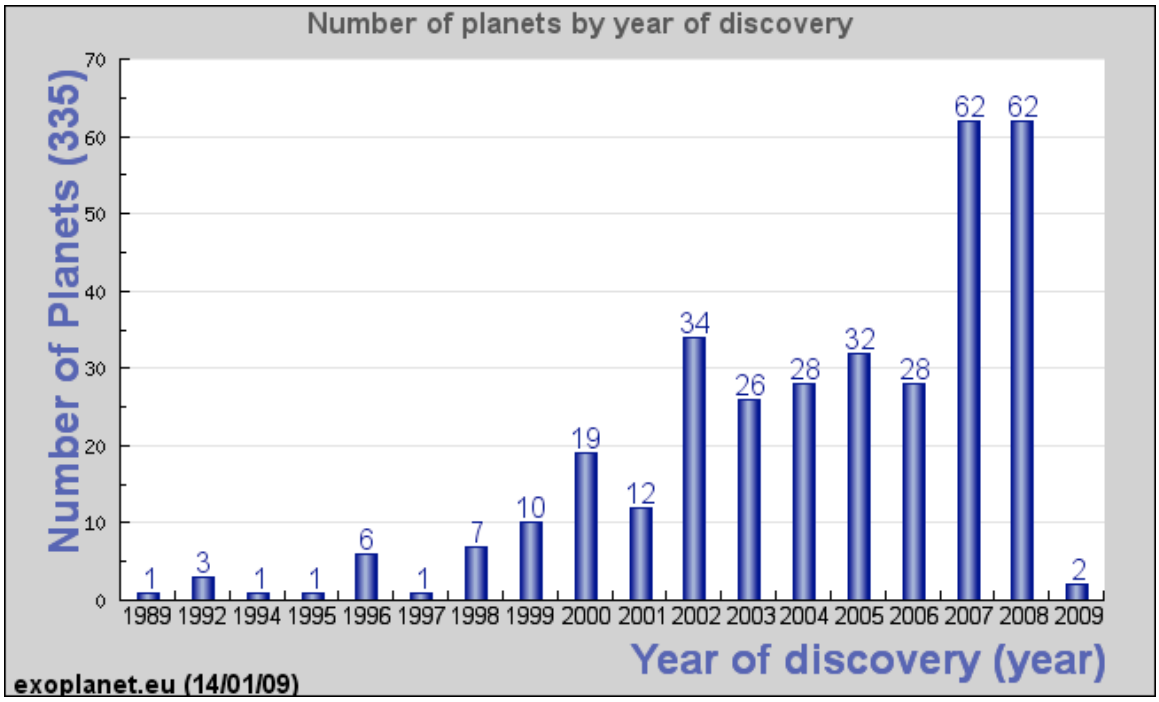
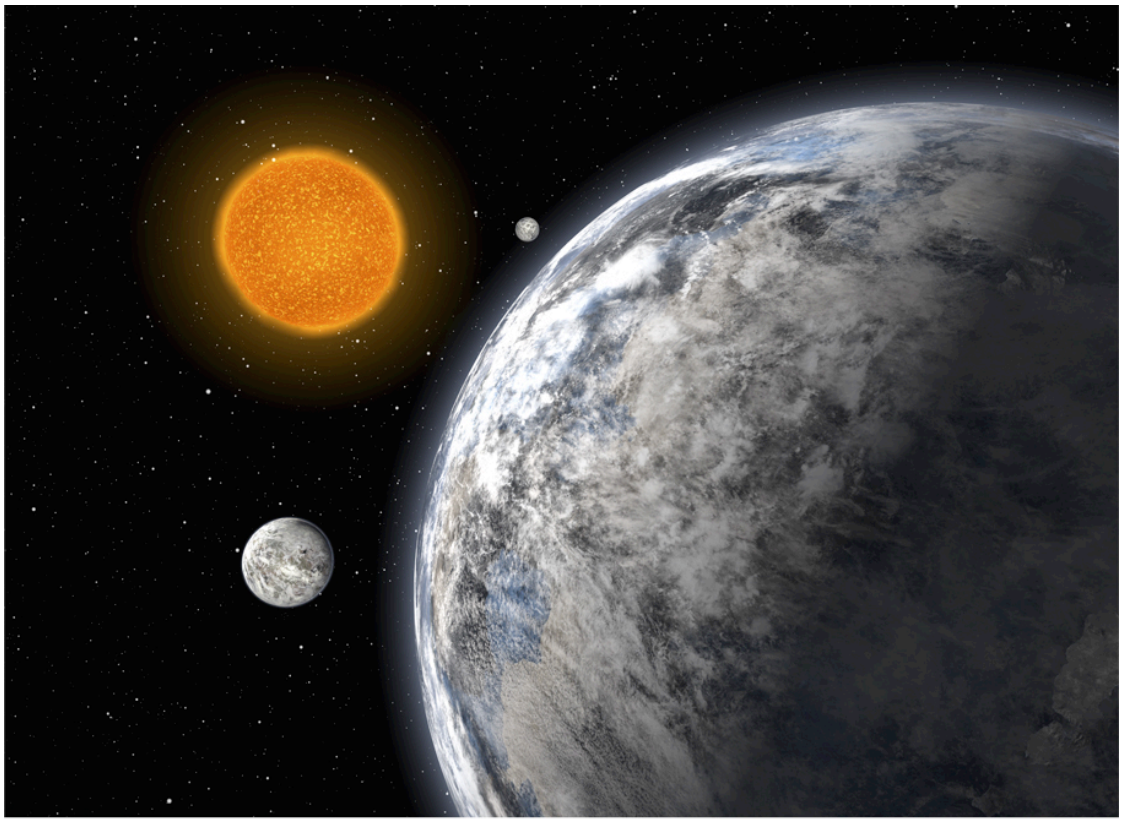


Figure 1. Number of extrasolar planets discovered per year. Histogram generated by Jean Schneider's Extrasolar Planets Encyclopedia web site (see http://exoplanet.eu/).

Extrasolar Planet Discoveries

Goals 1 and 7 of the 2008 Roadmap deal in large part with the desire to find evidence for life on extrasolar planets. Much of the current excitement in the field of extrasolar planets stems from the fact that well over 330 planetary systems in orbit around stars in our Milky Way galaxy have already been detected (see Figure 1), and the pace of discovery

continues to accelerate. The planets detected to date range from exotic bodies unlike anything in our Solar System (e.g., the cinder-like planets in orbit around pulsars, the remnants of massive star evolution) to worlds that are more reassuringly familiar. In the latter category, we now have excellent evidence for the existence of gas giant planets, similar to Jupiter and Saturn, ice giant planets similar to Uranus and Neptune (i.e., the cold super-Earths found by microlensing), and hot and warm super-Earths that appear to be analogous to the terrestrial planets Mercury, Venus, Earth, and Mars. In fact, these hot and warm super-Earths appear to be incredibly commonplace, with some estimates being that such worlds are present around about 1/3 of all stars like the Sun (Mayor et al. 2009).



A Trio of Super-Earths
(Artist's Impression)

ESO Press Photo 19a/08 (16 June 2008)

Figure 2. Artist's impression of the trio of super-Earths discovered by an European team headed by Michel Mayor (Geneva Observatory) using the HARPS spectrograph on ESO's 3.6-m telescope at La Silla, Chile, after 5 years of monitoring. The three planets, having 4.2, 6.7, and 9.4 times the mass of the Earth, orbit the star HD 40307 with periods of 4.3, 9.6, and 20.4 days, respectively. (Image courtesy of the European Southern Observatory, ESO. From M. Mayor et al. 2009, Astronomy & Astrophysics, volume 493, p. 639.)

One star, HD 40307 (see Figure 2), in fact appears to be orbited by not one or two, but by *three* super-Earths. These discoveries heighten the desire by worldwide astronomers to build space telescopes capable of detecting and characterizing Earth-like, inhabitable planets in the coming decades. Because of their high costs, these efforts will benefit from strong international collaborations between all interested space-faring nations. In the meantime, our knowledge of habitable exoplanets is best informed by a combination of continuing the present ground-based planet search efforts that are taking the census of exoplanets in our neighborhood of the galaxy and theoretical work on what the census of known, detectable exoplanets implies about the frequency of presently undetectable, habitable worlds. The successful launch of NASA's Kepler Space Telescope on March 6, 2009 means that within about four years, we will have a good estimate of the frequency of Earth-like planets towards the constellations Cygnus and Lyra, and it will then be up to future ground- and space-based telescopes to search for and characterize the habitable worlds in the Earth's immediate neighborhood, where they are most susceptible to study. After eons of speculation, we are about to learn how crowded the universe is.

Planetary Science Formation Focus Group Meeting

In order to better assess the opportunities presented by the various proposed and existing space- and ground-based telescopes, the PSFFG held an all-day meeting on January 7, 2009, in conjunction with the American Astronomical Society (AAS) meeting in Long Beach, California. The meeting consisted of invited presentations by representatives of most of the space- and ground-based telescopes thought to be of relevance to the astronomical aspects of the 2008 Roadmap. Each presenter was asked to evaluate how their mission would be able to address the Roadmap goals listed above. Roger Blandford, chair of Astro2010, stated in his Town Hall talk to the AAS on January 6 that JWST and SOFIA would *not* be subject to prioritization in the Astro2010 survey, so these two missions were not prioritized. While not strictly of direct concern for the Planet2011 survey, this prioritization list is included as an Appendix in order to provide some insight to the Planets2011 participants about the incredibly large range of present and proposed telescopes that are capable of making significant contributions to the study of habitable worlds outside the solar system. It is not too bold to state that the field of exoplanets, born in the mid-1990s and now just over a decade old, has grown in the interim to become one of the most vibrant, youthful, and challenging areas of planetary science and astronomy. Providing for the continued health and growth of exoplanetary science should be a major goal of both the Astro2010 and Planet2011 surveys.

Final Recommendations

We recommend that the Planet2011 Decadal Survey place a high priority on continued, even expanded, support of the Research & Analysis programs that fund the efforts of exoplanet theorists, laboratory workers, and observers through NASA's Astrobiology Institute, Cosmochemistry, Exobiology, Origins of Solar Systems, Outer Planets, and Planetary Geology & Geophysics Programs, as well as the NSF's Astronomy and Astrophysics Research Grants Program, where exoplanetary science is supported.

APPENDIX: *Assessments of Value of Specific Missions to Astrobiology Roadmap*

We did not attempt to summarize the specific measurement capabilities proposed for the various missions, their risks with regard to technical difficulty, cost, and schedule, or any of the other major factors that will help to determine in the end the prioritization of missions that is the ultimate product of the Astro2010 survey. Rather, we will simply accepted as fact what the missions are claiming to be able to accomplish, without trying to assess whether or not these claims are in fact realizable. We were content to assign a symbolic grade to each mission with respect to the extent to which its objectives would be able to make a significant contribution to the Goals and Objectives of the 2008 Astrobiology Roadmap.

	Assessments of Value to 2008 Roadmap		
Missions	Goal 1	Goal 3	Goal 7
Current Missions:			
Warm SST	+	--	--
HST post-SM4	+	+	+
Kepler	*	--	--
Herschel	--	+	--
Proposed Space Missions:			
SIM Lite	*	--	--
Terrestrial Planet Finder - C	*	--	*
Terrestrial Planet Finder - I	*	*	*
Space Strategic Mission Concepts:			
ASPIRE	--	*	+
THEIA	*	--	*
ATLAST	*	--	*
EPIC	+	--	+
NWO	*	+	*
DAVINCI	*	--	*
PECO	+	--	+
ACCESS	+	--	+
Ground-based Telescopes:			
GSMT	+	+	+
ALMA	+	+	+
Small Explorer Mission:			
TESS	+	--	--

The assessments are given as symbols as follows:

- * = highly valuable
- + = valuable
- -- = not relevant for this goal.